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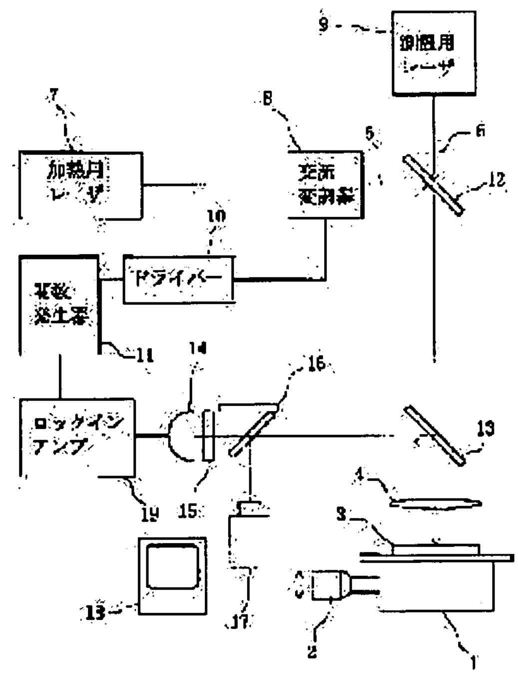
(54) MEASURING APPARATUS FOR THERMOPHYSICAL PROPERTY IN VERY SMALL REGION

(57)Abstract:

PROBLEM TO BE SOLVED: To obtain a measuring apparatus by which the thermophysical property in a very small region on the surface of a sample is measured with high spatial resolution.

SOLUTION: A metal thin film is formed on the surface of a sample 3. In order to heat the surface of the sample, a laser beam 5 for heating, which is AC-modulated by a modulator 8 and a laser beam 6 for temperature measurement, with which the surface of the sample is irradiated are condensed in nearly the same position on the surface of the sample through a micro-optical system 4. The reflected light of the laser beam for temperature measurement, at this time is detected. On the basis of the reflected light of the laser beam for temperature measurement, a change in the temperature of the surface of the sample is detected, its phase delay and its relative intensity are measured, and the thermophysical property value in a very small region of the sample is calculated. When the sample is moved two-dimensionally, the two-dimensional distribution of a local thermophysical property value can be found.



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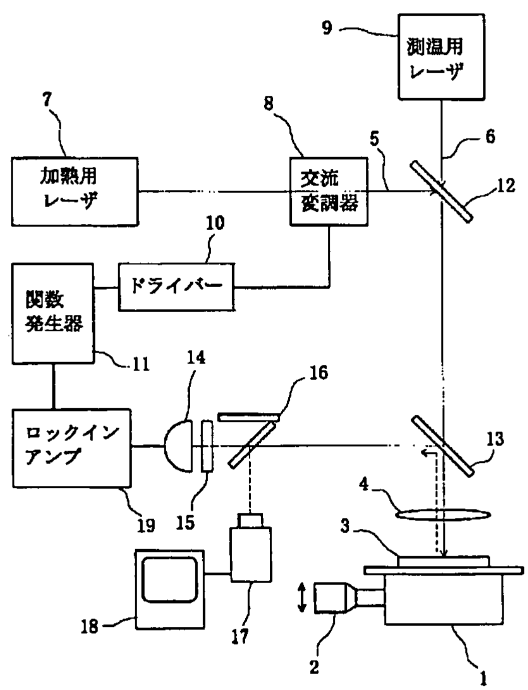
最終頁に続く

(54)【発明の名称】　微小領域熱物性測定装置

(57)【要約】
【課題】　試料表面の微小領域の熱物性を高い空間分解能により測定すること。
【解決手段】　試料3の表面に金属薄膜を形成し、その試料表面を加熱する為、変調器8で交流変調した加熱用レーザビーム5と加熱した試料表面に照射する測温用レーザビーム6とを顕微光学系4を通して試料表面のほぼ同一位置に集光させ、その時の測温用レーザビームの反射光を検出する。測温用レーザビームの反射光から試料表面の温度変化を検出して位相遅れや相対強度を測定し、試料の微小領域の熱物性値を算出する。試料を二次元移動させることにより局所的な熱物性値の二次元分布が求められる。



1

【特許請求の範囲】

【請求項１】　試料表面を加熱する加熱用レーザビームを発する加熱用レーザと、
該加熱用レーザビームを交流変調する変調器と、
加熱した試料表面に照射する測温用レーザビームを発する測温用レーザと、
前記両レーザビームを前記試料表面のほぼ同一位置に集光させる顕微鏡光学系と、
前記測温用レーザビームの反射光を検出する手段と、
前記検出された反射光に基づいて試料の熱物性値を算出する手段とを備え、
前記試料表面の反射率の温度依存性を用いて試料表面の温度変化を検出することを特徴とする微小領域熱物性測定装置。

【請求項２】　前記測温用レーザビームの反射光強度変化の加熱用レーザビーム強度変化に対する位相遅れから熱物性値を算出することを特徴とする請求項１記載の微小領域熱物性測定装置。

【請求項３】　前記測温用レーザビームの反射光強度変化の加熱用レーザビーム強度変化に対する相対強度から熱物性値を算出することを特徴とする請求項１記載の微小領域熱物性測定装置。

【請求項４】　前記試料表面に金属薄膜を形成することを特徴とする請求項１から３のいずれか記載の微小領域熱物性測定装置。

【請求項５】　試料をＸ，Ｙステージに設置し、顕微光学系に対する相対位置を二次元的に移動させ、熱物性値の平面分布を測定することを特徴とする請求項１から４のいずれかに記載の微小領域熱物性測定装置。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は熱反射法を用いて微小領域の熱浸透率分布を測定する装置に関し、特に、試料表面の微小領域に加熱用レーザと測定用レーザを集光させ、その測定用レーザの反射光を検出して試料の熱物性値を算出する微小領域熱物性測定装置に関する。

【０００２】

【従来の技術】従来、熱伝導測定法にはレーザフラッシュ法が知られている。この方法は直径１０ｍｍ，厚さ１ｍｍ以上の試料サイズが必要であり、測定した熱伝導はその平均を示す熱物性値であった。産業界においてはより小さな範囲、即ちミクロン単位の熱物性値の分布を知りたい要求はあったが、実用的な方法はなかった。薄膜は工業的に広く使用されており、特に半導体電子デバイスや記録媒体は集積度及び性能向上のために微細構造化、複雑化が進んでいる。これらを構成する微小な各素材の熱物性値はデバイスの熱設計において必要とされるが、一般的にその測定はバルク材料の測定に比べて難しい。１マイクロメートル以下の薄膜の熱拡散率を計測するためにピコ秒パルスレーザを用いた「ピコ秒サーモリフレクタンス法薄膜熱拡散率計測システム」が開発されている。ところが、本システムでは１点の熱拡散率を計測するのに約３０分かかり、試料表面の熱物性値分布の測定は時間的な制約のため、ほとんど不可能である。

2

【０００３】

【発明が解決しようとする課題】本発明の目的は、前記従来技術の問題点を解消し、試料表面の微小領域の熱物性を高い空間分解能により測定することができる微小領域熱物性測定装置を提供することにある。

【０００４】

【課題を解決するための手段】請求項１の発明に係る微小領域熱物性測定装置は、試料表面を加熱する加熱用レーザビームを発する加熱用レーザと、該加熱用レーザビームを交流変調する変調器と、加熱した試料表面に照射する測温用レーザビームを発する測温用レーザと、両レーザビームを試料表面のほぼ同一位置に集光させる顕微鏡光学系と、測温用レーザビームの反射光を検出する手段と、検出された反射光に基づいて試料の熱物性値を算出する手段とを備え、試料表面の反射率の温度依存性を用いて試料表面の温度変化を検出するようにした構成にある。また、請求項２の発明は、請求項１の発明において、測温用レーザビームの反射光強度変化の加熱用レーザビーム強度変化に対する位相遅れから熱物性値を算出するようにした構成にある。また、請求項３の発明は、請求項１の発明において、測温用レーザビームの反射光強度変化の加熱用レーザビーム強度変化に対する相対強度から熱物性値を算出するようにした構成にある。また、請求項４の発明は、請求項１から３の発明において、試料表面に金属薄膜を形成した構成にある。更に、請求項５の発明は、請求項１から４のいずれかの発明において、試料をＸ，Ｙステージに設置し、顕微光学系に対する相対位置を二次元的に移動させ、熱物性値の平面分布を測定するようにした構成にある。

【０００５】

【発明の作用】請求項１の発明によれば、交流変調した加熱用レーザビームを数マイクロメートルのスポット径で試料表面に集光加熱する。試料の表面温度は熱拡散により加熱の交流変動から位相遅れの変化を示す。その変化の大きさは試料の熱物性値によって定まる。加熱用レーザビームの同一位置に測温用レーザビームを集光すると、その反射光の強度は試料表面の温度変化に比例して変化する。従って、検出手段で検出した測温用レーザビームの反射光に対する出力を加熱用レーザビームの強度変化を参照信号としてロックイン増幅することにより試料表面の周期的温度変化の加熱用レーザビームの強度の周期的変化に対する位相遅れと相対強度が測定される。測定された位相遅れと相対強度から試料の局所的な熱物性値が算出される。請求項２の発明によれば、測温用レーザビームの強度は試料表面の温度変化に比例して変化する。加熱用レーザビームに対する試料の吸収係数αが

大きく、且つ熱拡散率κが大きいほど試料表面の温度変化の位相遅れは小さいので、測温用レーザビームの反射光強度変化の加熱用レーザビーム強度変化に対する位相遅れから$\alpha^2\kappa$が求められる。請求項3の発明によれば、測温用レーザビームの強度は試料表面の温度変化に比例して変化する。加熱用レーザビームに対する試料の吸収係数αが大きく、且つ熱拡散率κが大きいほど試料表面の温度変化は大きいので、測温用レーザビームの反射光強度変化の加熱用レーザビーム強度変化に対する相対強度から$\alpha^2\kappa$が求められる。請求項4の発明によれば、加熱用レーザビームおよび測温用レーザビームに対する吸収係数が小さい試料、または測温用レーザビームの反射率の温度係数が小さい試料に対しても、その表面に金属薄膜を形成することによりサーモリフレクタンス測定が実現される。請求項2の発明において、測温用レーザビームの加熱用レーザビームに対する位相遅れは金属薄膜の熱容量Cが小さく、試料の熱浸透率b_sが大きいほど小さいので、測温用レーザビームの反射光強度変化の加熱用レーザビーム強度変化に対する位相遅れからC/b_sが求められる。また請求項3の発明において、測温用レーザビームの加熱用レーザビームに対する相対強度は金属薄膜の熱容量Cが小さく、試料の熱浸透率b_sが大きいほど大きいので、測温用レーザビームの反射光強度変化の加熱用レーザビーム強度変化に対する相対強度からC/b_sが求められる。請求項5の発明によれば、X，Yステージにより試料の相対位置を操作しつつ位相遅れと相対強度の測定を継続することにより局所的な熱物性値の二次元分布が求められる。

【0006】

【発明の実施の態様】本発明の実施例について図面を参照しながら説明する。先ず、本発明の微小領域熱物性測定装置の測定原理を説明する。薄膜・基板2層モデルを考える。ここで、薄膜は金属薄膜、基板は対象となる試料にそれぞれ対応する。角周波数ωの正弦的な強度変調を受けた加熱光が試料表面に施された厚さd、熱拡散率k_f、熱浸透率b_fの金属薄膜に照射し、加熱される。このとき、表面の温度応答は加熱光に対してある位相遅れδを伴った角周波数ωの周期的な応答になる。試料の熱浸透率が大きいほど、または角周波数ωが小さいほど、表面温度応答の加熱光に対する位相差は小さくなる。

【0007】試料の局所熱浸透率は、図1に示した薄膜・基板2層モデルに基づいて計算することができる。基板は半無限の厚みとし、熱は厚さ方向のみ拡散することを仮定する。周期加熱F(t)は下記の式(1)で与えられるものとする。

【0008】

【数1】

$$F(t)=\sin\omega t \qquad (1)$$

このとき、表面温度応答のラプラス変換T(ξ)は次の式(2)で表される。

【0009】

【数2】

$$\tilde{T}(\xi)=\frac{1}{b_s\sqrt{\xi}}\frac{\omega}{\omega^2+\xi^2}\frac{\coth(\sqrt{\xi\tau_f})+\beta}{\coth(\sqrt{\xi\tau_f})+\beta^{-1}} \qquad (2)$$

b_sは基板(試料)の熱浸透率である。ここで、τ_fは薄膜層の熱拡散についての特性時間、$\tau_f=d^2/k_f$、βは薄膜に対する基板の熱浸透率比である。式(2)を逆ラプラス変換すると、表面温度応答は一般に以下の式により記述できる。

【0010】

【数3】

$$T(t)=A\sin(\omega t-\delta) \qquad (3)$$

【0011】

【数4】

$$\delta=\frac{3}{4}\pi+\arctan\left(\frac{\cosh^2\sqrt{\frac{\omega\tau_f}{2}}}{\cos^2\sqrt{\frac{\omega\tau_f}{2}}}\times\frac{\left(\tanh\sqrt{\frac{\omega\tau_f}{2}}+\beta\right)\left(\tanh\sqrt{\frac{\omega\tau_f}{2}}+\beta^{-1}\right)}{(\beta-\beta^{-1})\tan\sqrt{\frac{\omega\tau_f}{2}}}\right) \qquad (4)$$

【0012】ここで、δは周期加熱に対する表面温度応答の位相遅れを示す。薄膜の表から裏側までの熱拡散の特性時間d^2/k_fが加熱光の変調周期ωに比べて十分小さく、薄膜に対する基板の熱浸透率比βが十分小さいとき、表面位相応答式(3)は、近似的に次のようになる。

【0013】

【数5】

$$\delta=\arctan\left(-\frac{1+\sqrt{\frac{\omega\tau_s}{2}}}{\sqrt{\frac{\omega\tau_s}{2}}}\right)+\frac{3}{4}\pi \qquad (5)$$

$$\tau_s=\frac{b_f^2}{b_s^2}\frac{d^2}{\kappa_f}$$

ここで、τ_sは基板内の熱拡散を表す特性時間である。(5)式によると加熱光に対する温度応答の位相遅れδは$\omega\tau_s$が0から∞まで変化したとき、45°から90°の間で変化する。

【0014】次に測温用レーザビームの反射光強度変化

の加熱用レーザビーム強度変化に対する相対強度の算出を説明する。振幅１の変調された単位面積当たりの熱流を

【００１５】

【数６】

$$F(t)=\sin\omega t \tag{1}$$

このとき、表面温度応答のラプラス変換は、

【００１６】

【数７】

$$\tilde{T}(\xi)=\frac{1}{b_s\sqrt{\xi}}\frac{\omega}{\omega^2+\xi^2}\frac{\coth(\sqrt{\xi\tau_f})+\beta}{\coth(\sqrt{\xi\tau_f})+\beta^{-1}} \tag{2}$$

$$\tau_f=\frac{d^2}{\kappa_f} \tag{3}$$

ここで、τ_f：薄膜の熱拡散特性時間

（２）はβ、τ_fともに充分小さいとき、

【００１７】

＊【数８】

$$\tilde{T}(\xi)=\frac{1}{b_s\sqrt{\xi}}\frac{\omega}{\omega^2+\xi^2}\frac{1}{1+\sqrt{\xi\tau_s}} \tag{4}$$

$$\tau_s=\frac{b_f{}^2}{b_s{}^2}\frac{d^2}{\kappa_f} \tag{5}$$

と近似できる。（４）を逆ラプラス変換して以下の式を得る。

【００１８】

【数９】

$$T(t)=\frac{1}{b_s\sqrt{\xi}}\cdot\frac{\phi\sin\left(\omega t-\frac{3}{4}\pi\right)+(1+\phi)\cos\left(\omega t-\frac{3}{4}\pi\right)}{\phi^2+(1+\phi)^2} \tag{6}$$

$$\phi=\sqrt{\frac{\omega\tau_s}{2}} \tag{7}$$

表面温度は一般的に以下のように書ける。

【００１９】

【数１０】

$$T(t)=A\sin(\omega t-\delta) \tag{8}$$

計算の便宜上、以下を導入する。

【００２０】

【数１１】

$$\delta=\frac{3}{4}\pi+\delta' \tag{9}$$

（６），（８），（９）より

【００２１】

【数１２】

$$A\cos\delta'=\frac{\phi}{b_s\sqrt{\omega}\{\phi^2+(1+\phi)^2\}} \tag{10}$$

$$A\sin\delta'=-\frac{1+\phi}{b_s\sqrt{\omega}\{\phi^2+(1+\phi)^2\}} \tag{11}$$

（１０），（１１）より

※【００２２】

【数１３】

$$\tan\delta'=-\frac{1+\phi}{\phi} \tag{12}$$

（７），（９），（１２）より

【００２３】

【数１４】

$$\delta=\frac{3}{4}\pi+\arctan\left(-\frac{1+\sqrt{\frac{\omega\tau_s}{2}}}{\sqrt{\frac{\omega\tau_s}{2}}}\right) \tag{13}$$

（１０），（１１）より

【００２４】

【数１５】

$$A=\frac{1}{b_s\sqrt{\omega}}\cdot\frac{1}{\sqrt{\phi^2+(1+\phi)^2}} \tag{14}$$

（２）を近似せずに逆ラプラス変換して計算すると

【００２５】

★【数１６】

$$\delta=\frac{3}{4}\pi+\arctan\left(\frac{\cosh^2\sqrt{\frac{\omega\tau_f}{2}}}{\cos^2\sqrt{\frac{\omega\tau_f}{2}}}\cdot\frac{\left(\tanh\sqrt{\frac{\omega\tau_f}{2}}+\beta\right)\left(\tanh\sqrt{\frac{\omega\tau_f}{2}}+\beta^{-1}\right)}{(\beta-\beta^{-1})\tan\sqrt{\frac{\omega\tau_f}{2}}}\right) \tag{15}$$

となる。当然（１５）に対応した振幅Ａも計算できる。

このとき、

☆【００２６】

【数１７】

$$A=\frac{(\beta^{-1}-\beta)\tan\psi\sqrt{1+\left(\frac{\cosh^2\psi}{\cos^2\psi}\cdot\frac{(\tanh\psi+\beta)(\tanh\psi+\beta^{-1})}{(\beta-\beta^{-1})\tan\psi}\right)^2}}{b_s\sqrt{\omega}\cosh^2\psi}\qquad(16)$$

$$\psi=\sqrt{\frac{\omega\tau_f}{2}}\qquad(17)$$

【0027】図2は本発明の微小領域熱物性測定装置のシステム構成を示す概念図である。X，Yステージ1はX，Y方向の二次元に移動自在な機構になっており、マイクロメータ2により上下方向の高さが微調整可能になっている。測定すべき試料3はX，Yステージに載置され、レーザ光が試料表面に集光するようマイクロメータ2により高さ調整を行う。試料3の表面には顕微鏡光学系4を通過した後に同一光軸上に重なった加熱用レーザビーム5と測温用レーザビーム6が照射される。

【0028】加熱用レーザビーム5は、例えば波長514．5nmのCWアルゴンレーザ等で構成される加熱用レーザ7から発せられ、交流変調器8により変調される。測温用レーザビーム6は、例えばCWヘリウムネオンレーザ等で構成される測温用レーザ9から発せられる。ドライバ10はファンクションジェネレータ11から出力される所定周波数の交流を加熱用レーザビームの変調に必要なパワーに処理し、交流変調器8に出力する。交流変調器8は加熱用レーザ7からの加熱用レーザビームをドライバ10から出力される交流により変調する。

【0029】顕微鏡光学系4の光軸上には第1ハーフミラー12と第2ハーフミラー13が配置されている。第1ハーフミラー12は加熱用レーザ7から発生される加熱用レーザビーム5を顕微鏡光学系4の光軸に一致して反射させ、また測温用レーザ9から発せられる測温用レーザビーム6を顕微鏡光学系4の光軸に一致して通過させるよう作用する。第2ハーフミラー13は第1ハーフミラー12により反射された加熱用レーザビーム5と第1ハーフミラー12を通過した測温用レーザビーム6を顕微鏡光学系4の光軸に一致して通過させると共に、試料表面で反射した加熱用レーザビーム5と測温用レーザビーム6を光ディテクタ14の入射光軸に一致して反射するよう作用する。ここで、光ディタクタ14は、例えばホトダイオード等により構成される。

【0030】第2ハーフミラー13で反射したレーザ光はバンドパスフィルタ15により加熱用レーザビーム5の反射光を遮断し、測温用レーザビーム6の反射光のみを通過させて光ディテクタ14で検出する。第2ハーフミラー13とバンドパスフィルタ15との間には第3ハーフミラー16が反射光の光軸から外れた位置と反射光の一部をCCDカメラ17の方向に反射させる位置に回動可能に配置されている。CCDカメラ17に入射した両反射光によりモニタ18上に像を映出し、この像を見ながら加熱用レーザビーム5と測温用レーザビーム6の＊試料表面上のスポットサイズ、位置合わせを行う。

【0031】ロックインアンプ19は光ディテクタ14で検出した測温用レーザビームの強度変化に応じた検出信号のうち、加熱用レーザビームの強度変化に比例する参照信号に同期した成分を増幅し、参照信号に対する反射光の位相遅れδを得る。局所熱浸透率は金属薄膜の熱物性値を既知として、実測した位相遅れδを（5）式に代入して計算する。

【0032】図3に厚さの異なるモリブデンの温度応答を示す。（4）式に基づいた計算値にはバルク材料の値を用いた。測定された位相遅れは計算値と同様にモリブデン薄膜の膜厚とともに、増大している。モリブデン薄膜に対するガラス基板の熱浸透率比βは小さいので、（5）式に基づいて、測定で得られた位相差から求めたガラス基板の熱浸透率を表1に示す。

【0033】

【表1】

表1

厚み(nm)	位相遅れ (°)	$bs(Js^{0.5}/m^2K)$
Bulk	-	1338*
50	51.6	1700
100	59.8	1250
200	69.7	1050
500	82.0	730

【0034】本発明はマイクロ・エレクトロニクス関係の記録媒体、DVD光ディスク、MO光磁気ディスク、熱電素子、LSIのCPU及びRAM、半導体レーザ、LED、パワートランジスタなど、又素材として複合材料、特に原子力分野や宇宙機の耐熱材料などに用いられるCCコンポジット、超伝導線材、種々のコーティング材、傾斜機能材料、複合材料など物性の異なる2種類以上の材料を組み合わせることにより個々の材料だけでは得られない優れた性質を実現した材料の熱物性値分布を測定するのに直接利用可能である。従来の熱設計をより詳細にできるようになる為、熱工学関係の産業資材における特性を飛躍的に向上させる。

【0035】

【発明の効果】本発明によれば、加熱用レーザビームを高速正弦波変調して加熱光とすることにより、局所熱浸透率分布が測定可能になるようにサーモリフレクタンス法の測定時間を短縮する。また、試料表面に金属薄膜を形成することにより、測定対象を金属のみならず、半導体、セラミックス、炭素材料などに拡大することができ

る。更に、表面温度応答を薄膜・基板２層系の解析に基づいて計算することで、金属薄膜下の基板の局所熱浸透率が算出される。

【図面の簡単な説明】

【図１】薄膜・基板２層モデルの熱拡散の特性を表すパラメータの説明図である。

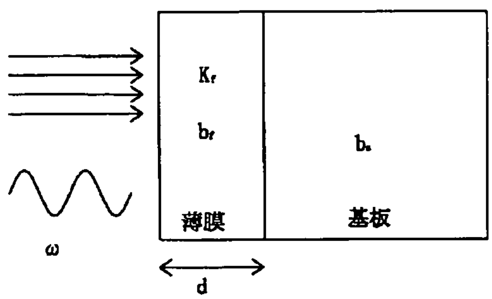
【図２】本発明の微小領域熱物性測定装置のシステム構成を示す概念図である。

【図３】厚さに対する位相遅れの関係を示す図である。

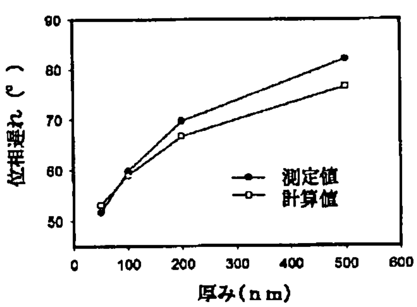
【符号の説明】

1　X，Yステージ
2　マイクロメータ
3　試料
4　顕微鏡光学系
12，13，16　ハーフミラー
14　光ディテクタ
15　バンドパスフィルタ
17　ＣＣＤカメラ
18　モニタ

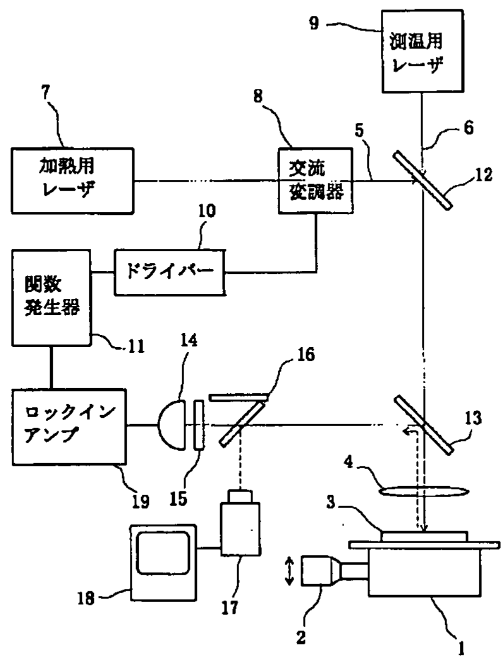
【図１】



【図３】



【図２】



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Ｆターム(参考)　2G040 AB05 AB08 BA26 CA02 CA12
CA23 DA05 DA12 DA15 DA24
EA06 EB02 EC04 HA16

CLAIMS

[Claim(s)]
[Claim 1] The laser for heating which emits the laser beam for heating which heats a sample front face, and the modulator which carries out the alternating current modulation of this laser beam for heating, The laser for temperature measurement which emits the laser beam for temperature measurement which irradiates the heated sample front face, Said both laser beams The microscope optical system on said front face of a sample which the same location is made to condense mostly, The minute field thermal property measuring device characterized by having a means to detect the reflected light of said laser beam for temperature measurement, and a means to compute the thermal property value of a sample based on said detected reflected light, and detecting the temperature change on the front face of a sample using the temperature dependence of the reflection factor on said front face of a sample.
[Claim 2] The minute field thermal property measuring device according to claim 1 characterized by computing a thermal property value from the phase lag over the laser beam change for heating of a reflected light change of said laser beam for temperature measurement on the strength on the strength.
[Claim 3] The minute field thermal property measuring device according to claim 1 characterized by computing a thermal property value from the relative intensity to the laser beam change for heating of a reflected light change of said laser beam for temperature measurement on the strength on the strength.
[Claim 4] Claims 1-3 characterized by forming a metal thin film in said sample front face are the minute field thermal property measuring devices of a publication either.
[Claim 5] A minute field thermal property measuring device given in either of claims 1-4 characterized by installing a sample in X and Y stage, moving the relative position to micro optical system two-dimensional, and measuring flat-surface distribution of a thermal property value.

[Translation done.]

* NOTICES *

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Field of the Invention] This invention relates to the minute field thermal property measuring device which computes the thermal property value of a sample by making the minute field on the front face of a sample condense the laser for heating, and the laser for measurement, and detecting the reflected light of the laser for measurement especially about the equipment which measures heat permeability distribution of a minute field using a thermal reflex method.
[0002]
[Description of the Prior Art] Conventionally, the laser flash method is known by the heat-conduction measuring method. The diameter of 10mm and the sample size beyond thickness 1mm were required for this approach, and measured heat conduction was a thermal property value which shows that average. Although there was a demand which wants to know distribution of the thermal property value of the smaller range, i.e., a micron unit, in the industrial world, there was no practical approach. The thin film is used widely industrially and, especially as for a semi-conductor electron device and a record medium, fine-structure-izing and complication are progressing for a degree of integration and the improvement in the engine performance. Although the thermal property value of each minute raw material which constitutes these is needed in the thermal design of a device, generally the measurement is difficult compared with measurement of a bulk material. In order to measure the thermal diffusivity of a thin film 1 micrometer or less, the "picosecond thermostat reflectance method thin film thermal-diffusivity instrumentation system" which used the picosecond pulse laser is developed. However, it takes about 30 minutes to measure the thermal diffusivity of one point in this system, and measurement of the thermal property value distribution on the front face of a sample is almost impossible because of time constraint.
[0003]
[Problem(s) to be Solved by the Invention] The object of this invention cancels the trouble of said conventional technique, and is to offer the minute field thermal property measuring device which can measure the thermal property of the minute field on the front face of a sample with high spatial resolving power.
[0004]
[Means for Solving the Problem] The minute field thermal property measuring device concerning invention of claim 1 The laser for heating which emits the laser beam for heating which heats a sample front face, and the modulator which carries out the alternating current modulation of this laser beam for heating, The laser for temperature measurement which emits the laser beam for temperature measurement which irradiates the heated sample front face, Both laser beams The microscope optical system on the front face of a sample which the same location is made to condense mostly, It has a means to detect the reflected light of the laser beam for temperature measurement, and a means to compute the thermal property value of a sample based on the detected reflected light, and is in the configuration which detected the temperature change on the front face of a sample using the temperature dependence of the reflection factor on the front face of a sample. Moreover, in invention of claim 1, the configuration which computed the thermal property value from the phase lag over the laser beam change for heating of a reflected light change of the laser beam for temperature measurement on the strength on the strength has invention of claim 2. Moreover, in invention of claim 1, the configuration which computed the thermal property value from the relative intensity to the laser beam change for heating of a reflected light change of the laser beam for temperature measurement on the strength on the strength has invention of claim 3. Moreover, in invention of claims 1-3, the configuration in which the metal thin film was formed on the sample front face has invention of claim 4. Furthermore, in one invention of claims 1-4, invention of claim 5 installs a sample in X and Y stage, moves the relative position to micro optical system two-dimensional, and is in the configuration which measured flat-surface distribution of a thermal property value.
[0005]
[Function of the Invention] According to invention of claim 1, condensing heating of the laser beam for heating which

carried out the alternating current modulation is carried out on a sample front face with the several micrometers diameter of a spot. The skin temperature of a sample shows change of phase lag from alternating current fluctuation of heating by thermal diffusion. The magnitude of the change becomes settled with the thermal property value of a sample. If the laser beam for temperature measurement is condensed in the same location of the laser beam for heating, the reinforcement of the reflected light will change in proportion to the temperature change on the front face of a sample. Therefore, the phase lag and strong relative intensity to periodic change of the laser beam for heating of temperature cycling on the front face of a sample are measured by carrying out lock-in magnification of the output to the reflected light of the laser beam for temperature measurement detected with the detection means, using change of the laser beam for heating on the strength as a reference sign. The local thermal property value of a sample is computed from the measured phase lag and relative intensity. According to invention of claim 2, the reinforcement of the laser beam for temperature measurement changes in proportion to the temperature change on the front face of a sample. Since the phase lag of the temperature change on the front face of a sample is so small that the absorption coefficient alpha of the sample to the laser beam for heating is large and a thermal diffusivity kappa is large, alpha2kappa is called for from the phase lag over the laser beam change for heating of a reflected light change of the laser beam for temperature measurement on the strength on the strength. According to invention of claim 3, the reinforcement of the laser beam for temperature measurement changes in proportion to the temperature change on the front face of a sample. Since the temperature change on the front face of a sample is so large that the absorption coefficient alpha of the sample to the laser beam for heating is large and a thermal diffusivity kappa is large, alpha2kappa is called for from the relative intensity to the laser beam change for heating of a reflected light change of the laser beam for temperature measurement on the strength on the strength. According to invention of claim 4, thermostat reflectance measurement is realized by forming a metal thin film in the front face also to a sample with the small absorption coefficient to the laser beam for heating, and the laser beam for temperature measurement, or a sample with the small temperature coefficient of the reflection factor of the laser beam for temperature measurement. In invention of claim 2, since the phase lag over the laser beam for heating of the laser beam for temperature measurement has the small heat capacity C of a metal thin film, and it is so small that the heat permeability bs of a sample is large, C/bs is calculated from the phase lag over the laser beam change for heating of a reflected light change of the laser beam for temperature measurement on the strength on the strength. Moreover, in invention of claim 3, since it is so large that the relative intensity to the laser beam for heating of the laser beam for temperature measurement has the small heat capacity C of a metal thin film and the heat permeability bs of a sample is large, C/bs is calculated from the relative intensity to the laser beam change for heating of a reflected light change of the laser beam for temperature measurement on the strength on the strength. According to invention of claim 5, 2-dimensional distribution of a local thermal property value is searched for by continuing measurement of phase lag and relative intensity, operating the relative position of a sample by X and Y stage.

[0006]

[The mode of implementation of invention] It explains referring to a drawing about the example of this invention. First, the measurement principle of the minute field thermal property measuring device of this invention is explained. A thin film and a substrate two-layer model are considered. Here, it corresponds to the target sample [a thin film turns into a metal thin film, and / substrate], respectively. The sine-intensity modulation of angular frequency omega is irradiated at the metal thin film of thickness d given to carrier beam heating light on the sample front face, a thermal diffusivity kf, and the heat permeability bf, and it is heated. At this time, a surface temperature response turns into a periodic response of the angular frequency omega accompanied by certain phase lag delta to heating light. The phase contrast over the heating light of a skin temperature response becomes small, so that angular frequency omega is so small that the heat permeability of a sample is large.

[0007] The partial heat permeability of a sample is calculable based on the thin film and substrate two-layer model shown in drawing 1 . A substrate is made into the thickness of half-infinity and it assumes that heat diffuses only the thickness direction. Periodic heating F (t) shall be given by the following formula (1).

[0008]

[Equation 1]

$$F(t) = \sin \omega t \qquad (1)$$

At this time, Laplace-transform T (xi) of a skin temperature response is expressed with the following formula (2).

[0009]

[Equation 2]

$$\tilde{T}(\xi) = \frac{1}{b_s\sqrt{\xi}}\frac{\omega}{\omega^2+\xi^2}\frac{\coth(\sqrt{\xi\tau_f})+\beta}{\coth(\sqrt{\xi\tau_f})+\beta^{-1}} \qquad (2)$$

bs is the heat permeability of a substrate (sample). Here, tauf is the property time amount about the thermal diffusion of a thin film layer, and the heat permeability ratio [as opposed to a thin film in tauf=d2/kf and beta] of a substrate. If inverse Laplace transform of the formula (2) is carried out, generally the following formulas can describe a skin temperature response.
[0010]
[Equation 3]

$$T(t) = A\sin(\omega t - \delta) \qquad (3)$$

[0011]
[Equation 4]

$$\delta = \frac{3}{4}\pi + \arctan\left(\frac{\cosh^2\sqrt{\frac{\omega\tau_f}{2}}}{\cos^2\sqrt{\frac{\omega\tau_f}{2}}} \times \frac{\left(\tanh\sqrt{\frac{\omega\tau_f}{2}} + \beta\right)\left(\tanh\sqrt{\frac{\omega\tau_f}{2}} + \beta^{-1}\right)}{(\beta - \beta^{-1})\tan\sqrt{\frac{\omega\tau_f}{2}}} \right) \qquad (4)$$

[0012] Here, delta shows the phase lag of the skin temperature response to periodic heating. The property time amount d2/kf of the thermal diffusion from the table of a thin film to a background is small enough compared with the modulation period omega of heating light, and the heat permeability ratio beta of a surface phase response type (3) of a substrate to a thin film is as follows in approximation, when sufficiently small.
[0013]
[Equation 5]

$$\delta = \arctan\left(- \frac{1 + \sqrt{\frac{\omega\tau_s}{2}}}{\sqrt{\frac{\omega\tau_s}{2}}} \right) + \frac{3}{4}\pi \qquad (5)$$

$$\tau_s = \frac{b_f^2}{b_s^2}\frac{d^2}{\kappa_f}$$

Here, taus is the property time amount showing the thermal diffusion in a substrate. (5) According to the formula, phase lag delta of a temperature response to heating light changes between 45 degrees and 90 degrees, when omegataus changes from 0 to infinity.
[0014] Next, the calculation of relative intensity to the laser beam change for heating of a reflected light change of the laser beam for temperature measurement on the strength on the strength is explained. It is a heat flow rate per [by which the amplitude 1 was modulated] unit area [0015]
[Equation 6]

$$F(t) = \sin\omega t \qquad (1)$$

At this time, the Laplace transform of a skin temperature response is [0016].
[Equation 7]

$$\tilde{T}(\xi) = \frac{1}{b_s\sqrt{\xi}}\frac{\omega}{\omega^2 + \xi^2}\frac{\coth(\sqrt{\xi\tau_f}) + \beta}{\coth(\sqrt{\xi\tau_f}) + \beta^{-1}} \qquad (2)$$

$$\tau_f = \frac{d^2}{\kappa_f} \qquad (3)$$

Here, the thermal diffusion property time amount (2) of a tauf:thin film is [0017] when [when beta and tauf are

sufficient] small.
[Equation 8]

$$\tilde{T}(\xi) = \frac{1}{b_s\sqrt{\xi}} \frac{\omega}{\omega^2+\xi^2} \frac{1}{1+\sqrt{\xi\tau_s}} \qquad (4)$$

$$\tau_s = \frac{b_f^{\,2}}{b_s^{\,2}} \frac{d^2}{\kappa_f} \qquad (5)$$

It can approximate. Inverse Laplace transform of (4) is carried out, and the following formulas are obtained.
[0018]
[Equation 9]

$$T(t) = \frac{1}{b_s\sqrt{\xi}} \cdot \frac{\phi\sin\left(\omega t - \frac{3}{4}\pi\right) + (1+\phi)\cos\left(\omega t - \frac{3}{4}\pi\right)}{\phi^2 + (1+\phi)^2} \qquad (6)$$

$$\phi = \sqrt{\frac{\omega\tau_s}{2}} \qquad (7)$$

Generally skin temperature can be written as follows.
[0019]
[Equation 10]

$$T(t) = A\sin(\omega t - \delta) \qquad (8)$$

The expedient top of count and the following are introduced.
[0020]
[Equation 11]

$$\delta = \frac{3}{4}\pi + \delta' \qquad (9)$$

It is [0021] from (6), (8), and (9).
[Equation 12]

$$A\cos\delta' = \frac{\phi}{b_s\sqrt{\omega}\left\{\phi^2 + (1+\phi)^2\right\}} \qquad (10)$$

$$A\sin\delta' = -\frac{1+\phi}{b_s\sqrt{\omega}\left\{\phi^2 + (1+\phi)^2\right\}} \qquad (11)$$

It is [0022] from (10) and (11).
[Equation 13]

$$\tan\delta' = -\frac{1+\phi}{\phi} \qquad (12)$$

It is [0023] from (7), (9), and (12).
[Equation 14]

$$\delta = \frac{3}{4}\pi + \arctan\left(-\frac{1+\sqrt{\frac{\omega\tau_s}{2}}}{\sqrt{\frac{\omega\tau_s}{2}}}\right) \qquad (13)$$

It is [0024] from (10) and (11).
[Equation 15]

$$A = \frac{1}{b_s\sqrt{\omega}} \cdot \frac{1}{\sqrt{\phi^2 + (1+\phi)^2}} \qquad (14)$$

It is [0025] when it calculates by carrying out inverse Laplace transform, without approximating (2).
[Equation 16]

$$\delta = \frac{3}{4}\pi + \arctan\left(\frac{\cosh^2\sqrt{\frac{\omega\tau_f}{2}}}{\cos^2\sqrt{\frac{\omega\tau_f}{2}}} \cdot \frac{\left(\tanh\sqrt{\frac{\omega\tau_f}{2}}+\beta\right)\left(\tanh\sqrt{\frac{\omega\tau_f}{2}}+\beta^{-1}\right)}{(\beta-\beta^{-1})\tan\sqrt{\frac{\omega\tau_f}{2}}}\right) \quad (15)$$

It becomes. Naturally the amplitude A corresponding to (15) is calculable. At this time, it is [0026].
[Equation 17]

$$A = \frac{(\beta^{-1}-\beta)\tan\psi\sqrt{1+\left(\frac{\cosh^2\psi}{\cos^2\psi} \cdot \frac{(\tanh\psi+\beta)(\tanh\psi+\beta^{-1})}{(\beta-\beta^{-1})\tan\psi}\right)^2}}{b_s\sqrt{\omega}\cosh^2\psi} \quad (16)$$

$$\psi = \sqrt{\frac{\omega\tau_f}{2}} \quad (17)$$

[0027] Drawing 2 is the conceptual diagram showing the system configuration of the minute field thermal property measuring device of this invention. X and the Y stage 1 are the device which can move to two dimensions of X and the direction of Y freely, and fine adjustment of the height of the vertical direction is attained by the micrometer 2. The sample 3 which should be measured is laid in X and Y stage, and it performs height adjustment by the micrometer 2 so that a laser beam may condense on a sample front face. After passing the microscope optical system 4 in the front face of a sample 3, the laser beam 5 for heating and the laser beam 6 for temperature measurement which lapped on the same optical axis are irradiated.
[0028] The laser beam 5 for heating is emitted from the laser 7 for heating which consists of CW argon laser with a wavelength of 514.5nm etc., and is modulated by the alternating current modulator 8. The laser beam 6 for temperature measurement is emitted from the laser 9 for temperature measurement which consists of CW He Ne laser etc. A driver 10 processes the alternating current of the predetermined frequency outputted from a function generator 11 to power required for the modulation of the laser beam for heating, and outputs it to the alternating current modulator 8. The alternating current modulator 8 modulates the laser beam for heating from the laser 7 for heating by the alternating current outputted from a driver 10.
[0029] On the optical axis of the microscope optical system 4, the 1st half mirror 12 and the 2nd half mirror 13 are arranged. The 1st half mirror 12 acts so that the laser beam 6 for temperature measurement which is made to reflect the laser beam 5 for heating generated from the laser 7 for heating in accordance with the optical axis of the microscope optical system 4, and is emitted from the laser 9 for temperature measurement may be passed in accordance with the optical axis of the microscope optical system 4. The 2nd half mirror 13 acts so that the laser beam 5 for heating and the laser beam 6 for temperature measurement which were reflected on the sample front face may be reflected in accordance with the incident light shaft of the optical detector 14, while passing the laser beam 5 for heating reflected by the 1st half mirror 12, and the laser beam 6 for temperature measurement which passed the 1st half mirror 12 in accordance with the optical axis of the microscope optical system 4. Here, optical DITAKUTA 14 is constituted by photo diode etc.
[0030] The laser beam reflected by the 2nd half mirror 13 intercepts the reflected light of the laser beam 5 for heating with a band pass filter 15, passes only the reflected light of the laser beam 6 for temperature measurement, and is detected by the optical detector 14. Between the 2nd half mirror 13 and a band pass filter 15, it is arranged rotatable in the location from which the 3rd half mirror 16 separated from the optical axis of the reflected light, and the location which reflects a part of reflected light in the direction of CCD camera 17. An image is projected on a monitor 18 by both the reflected lights that carried out incidence to CCD camera 17, and spot size on the sample front face of the laser beam 5 for heating and the laser beam 6 for temperature measurement and alignment are performed, looking at this image.
[0031] The lock-in amplifier 19 amplifies the component which synchronized with the reference sign which is proportional to a change of the laser beam for heating on the strength among the detecting signals according to a change of the laser beam for temperature measurement detected by the optical detector 14 on the strength, and obtains phase lag delta of the reflected light to a reference sign. Partial heat permeability calculates surveyed phase lag delta by substituting it for (5) types by making the thermal property value of a metal thin film into known.
[0032] The temperature response of the molybdenum with which thickness differs in drawing 3 is shown. (4) The value of a bulk material was used for the calculated value based on a formula. With the thickness of a molybdenum thin film, the measured phase lag is increasing like calculated value. Since the heat permeability ratio beta of a glass substrate to a molybdenum thin film is small, based on (5) types, the heat permeability of the glass substrate for which it asked from the phase contrast acquired by measurement is shown in a table 1.

[0033]
[A table 1]

表1

厚み(nm)	位相遅れ (°)	$bs(Js^{0.5}/m^2K)$
Bulk	-	1338*
50	51.6	1700
100	59.8	1250
200	69.7	1050
500	82.0	730

[0034] This invention A micro electronics-related record medium, a DVD optical disk, MO magneto-optic disk, a thermoelement, CPU and RAM of LSI, semiconductor laser, The CC composites used for composite material, especially a nuclear field, the heat-resisting material of a spacecraft, etc. as raw materials, such as LED and a power transistor, By combining two or more kinds of ingredients with which physical properties differ, such as a superconduction wire rod, various coating materials, a functionally gradient material, and composite material, although the thermal property value distribution of the ingredient which realized the outstanding property which is not acquired only with each ingredient is measured, it is directly available. In order to make the conventional thermal design to a detail more, the property in heat engineering-related industrial materials is raised by leaps and bounds.

[0035]

[Effect of the Invention] According to this invention, by carrying out the high-speed sine wave modulation of the laser beam for heating, and considering as heating light, the measuring time of the thermostat reflectance method is shortened so that partial heat permeability distribution may become measurable. Moreover, the measuring object is expandable not only to a metal but a semi-conductor, the ceramics, a carbon material, etc. by forming a metal thin film in a sample front face. Furthermore, the partial heat permeability of the substrate under a metal thin film is computed by calculating a skin temperature response based on the analysis of a thin film and a substrate two-layer system.

[Translation done.]

TECHNICAL FIELD

[Field of the Invention] This invention relates to the minute field thermal property measuring device which computes the thermal property value of a sample by making the minute field on the front face of a sample condense the laser for heating, and the laser for measurement, and detecting the reflected light of the laser for measurement especially about the equipment which measures heat permeability distribution of a minute field using a thermal reflex method.

[Translation done.]

* NOTICES *

PRIOR ART

[Description of the Prior Art] Conventionally, the laser flash method is known by the heat-conduction measuring method. The diameter of 10mm and the sample size beyond thickness 1mm were required for this approach, and measured heat conduction was a thermal property value which shows that average. Although there was a demand which wants to know distribution of the thermal property value of the smaller range, i.e., a micron unit, in the industrial world, there was no practical approach. The thin film is used widely industrially and, especially as for a semi-conductor electron device and a record medium, fine-structure-izing and complication are progressing for a degree of integration and the improvement in the engine performance. Although the thermal property value of each minute raw material which constitutes these is needed in the thermal design of a device, generally the measurement is difficult compared with measurement of a bulk material. In order to measure the thermal diffusivity of a thin film 1 micrometer or less, the "picosecond thermostat reflectance method thin film thermal-diffusivity instrumentation system" which used the picosecond pulse laser is developed. However, it takes about 30 minutes to measure the thermal diffusivity of one point in this system, and measurement of the thermal property value distribution on the front face of a sample is almost impossible because of time constraint.

[Translation done.]

EFFECT OF THE INVENTION

[Effect of the Invention] According to this invention, by carrying out the high-speed sine wave modulation of the laser beam for heating, and considering as heating light, the measuring time of the thermostat reflectance method is shortened so that partial heat permeability distribution may become measurable. Moreover, the measuring object is expandable not only to a metal but a semi-conductor, the ceramics, a carbon material, etc. by forming a metal thin film in a sample front face. Furthermore, the partial heat permeability of the substrate under a metal thin film is computed by calculating a skin temperature response based on the analysis of a thin film and a substrate two-layer system.

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TECHNICAL PROBLEM

[Problem(s) to be Solved by the Invention] The object of this invention cancels the trouble of said conventional technique, and is to offer the minute field thermal property measuring device which can measure the thermal property of the minute field on the front face of a sample with high spatial resolving power.

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[Translation done.]

MEANS

[Means for Solving the Problem] The minute field thermal property measuring device concerning invention of claim 1 The laser for heating which emits the laser beam for heating which heats a sample front face, and the modulator which carries out the alternating current modulation of this laser beam for heating, The laser for temperature measurement which emits the laser beam for temperature measurement which irradiates the heated sample front face, Both laser beams The microscope optical system on the front face of a sample which the same location is made to condense mostly, It has a means to detect the reflected light of the laser beam for temperature measurement, and a means to compute the thermal property value of a sample based on the detected reflected light, and is in the configuration which detected the temperature change on the front face of a sample using the temperature dependence of the reflection factor on the front face of a sample. Moreover, in invention of claim 1, the configuration which computed the thermal property value from the phase lag over the laser beam change for heating of a reflected light change of the laser beam for temperature measurement on the strength on the strength has invention of claim 2. Moreover, in invention of claim 1, the configuration which computed the thermal property value from the relative intensity to the laser beam change for heating of a reflected light change of the laser beam for temperature measurement on the strength on the strength has invention of claim 3. Moreover, in invention of claims 1-3, the configuration in which the metal thin film was formed on the sample front face has invention of claim 4. Furthermore, in one invention of claims 1-4, invention of claim 5 installs a sample in X and Y stage, moves the relative position to micro optical system two-dimensional, and is in the configuration which measured flat-surface distribution of a thermal property value.

[Translation done.]

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OPERATION

[Function of the Invention] According to invention of claim 1, condensing heating of the laser beam for heating which carried out the alternating current modulation is carried out on a sample front face with the several micrometers diameter of a spot. The skin temperature of a sample shows change of phase lag from alternating current fluctuation of heating by thermal diffusion. The magnitude of the change becomes settled with the thermal property value of a sample. If the laser beam for temperature measurement is condensed in the same location of the laser beam for heating, the reinforcement of the reflected light will change in proportion to the temperature change on the front face of a sample. Therefore, the phase lag and strong relative intensity to periodic change of the laser beam for heating of temperature cycling on the front face of a sample are measured by carrying out lock-in magnification of the output to the reflected light of the laser beam for temperature measurement detected with the detection means, using change of the laser beam for heating on the strength as a reference sign. The local thermal property value of a sample is computed from the measured phase lag and relative intensity. According to invention of claim 2, the reinforcement of the laser beam for temperature measurement changes in proportion to the temperature change on the front face of a sample. Since the phase lag of the temperature change on the front face of a sample is so small that the absorption coefficient alpha of the sample to the laser beam for heating is large and a thermal diffusivity kappa is large, alpha2kappa is called for from the phase lag over the laser beam change for heating of a reflected light change of the laser beam for temperature measurement on the strength on the strength. According to invention of claim 3, the reinforcement of the laser beam for temperature measurement changes in proportion to the temperature change on the front face of a sample. Since the temperature change on the front face of a sample is so large that the absorption coefficient alpha of the sample to the laser beam for heating is large and a thermal diffusivity kappa is large, alpha2kappa is called for from the relative intensity to the laser beam change for heating of a reflected light change of the laser beam for temperature measurement on the strength on the strength. According to invention of claim 4, thermostat reflectance measurement is realized by forming a metal thin film in the front face also to a sample with the small absorption coefficient to the laser beam for heating, and the laser beam for temperature measurement, or a sample with the small temperature coefficient of the reflection factor of the laser beam for temperature measurement. In invention of claim 2, since the phase lag over the laser beam for heating of the laser beam for temperature measurement has the small heat capacity C of a metal thin film, and it is so small that the heat permeability bs of a sample is large, C/bs is calculated from the phase lag over the laser beam change for heating of a reflected light change of the laser beam for temperature measurement on the strength on the strength. Moreover, in invention of claim 3, since it is so large that the relative intensity to the laser beam for heating of the laser beam for temperature measurement has the small heat capacity C of a metal thin film and the heat permeability bs of a sample is large, C/bs is calculated from the relative intensity to the laser beam change for heating of a reflected light change of the laser beam for temperature measurement on the strength on the strength. According to invention of claim 5, 2-dimensional distribution of a local thermal property value is searched for by continuing measurement of phase lag and relative intensity, operating the relative position of a sample by X and Y stage.
[0006]
[The mode of implementation of invention] It explains referring to a drawing about the example of this invention. First, the measurement principle of the minute field thermal property measuring device of this invention is explained. A thin film and a substrate two-layer model are considered. Here, it corresponds to the target sample [a thin film turns into a metal thin film, and / substrate], respectively. The sine-intensity modulation of angular frequency omega is irradiated at the metal thin film of thickness d given to carrier beam heating light on the sample front face, a thermal diffusivity kf, and the heat permeability bf, and it is heated. At this time, a surface temperature response turns into a periodic response of the angular frequency omega accompanied by certain phase lag delta to heating light. The phase contrast over the heating light of a skin temperature response becomes small, so that angular frequency omega is so small that the heat permeability of a sample is large.

[0007] The partial heat permeability of a sample is calculable based on the thin film and substrate two-layer model shown in drawing 1 . A substrate is made into the thickness of half-infinity and it assumes that heat diffuses only the thickness direction. Periodic heating F (t) shall be given by the following formula (1).
[0008]
[Equation 1]

$$F(t) = \sin \omega t \qquad (1)$$

At this time, Laplace-transform T (xi) of a skin temperature response is expressed with the following formula (2).
[0009]
[Equation 2]

$$\tilde{T}(\xi) = \frac{1}{b_s\sqrt{\xi}} \frac{\omega}{\omega^2 + \xi^2} \frac{\coth(\sqrt{\xi \tau_f}) + \beta}{\coth(\sqrt{\xi \tau_f}) + \beta^{-1}} \qquad (2)$$

bs is the heat permeability of a substrate (sample). Here, tauf is the property time amount about the thermal diffusion of a thin film layer, and the heat permeability ratio [as opposed to a thin film in tauf=d2/kf and beta] of a substrate. If inverse Laplace transform of the formula (2) is carried out, generally the following formulas can describe a skin temperature response.
[0010]
[Equation 3]

$$T(t) = A \sin(\omega t - \delta) \qquad (3)$$

[0011]
[Equation 4]

$$\delta = \frac{3}{4}\pi + \arctan\left(\frac{\cosh^2 \sqrt{\frac{\omega \tau_f}{2}}}{\cos^2 \sqrt{\frac{\omega \tau_f}{2}}} \times \frac{\left(\tanh\sqrt{\frac{\omega \tau_f}{2}} + \beta\right)\left(\tanh\sqrt{\frac{\omega \tau_f}{2}} + \beta^{-1}\right)}{(\beta - \beta^{-1}) \tan\sqrt{\frac{\omega \tau_f}{2}}} \right) \qquad (4)$$

[0012] Here, delta shows the phase lag of the skin temperature response to periodic heating. The property time amount d2/kf of the thermal diffusion from the table of a thin film to a background is small enough compared with the modulation period omega of heating light, and the heat permeability ratio beta of a surface phase response type (3) of a substrate to a thin film is as follows in approximation, when sufficiently small.
[0013]
[Equation 5]

$$\delta = \arctan\left(- \frac{1 + \sqrt{\frac{\omega \tau_s}{2}}}{\sqrt{\frac{\omega \tau_s}{2}}} \right) + \frac{3}{4}\pi \qquad (5)$$

$$\tau_s = \frac{b_f^2}{b_s^2} \frac{d^2}{\kappa_f}$$

Here, taus is the property time amount showing the thermal diffusion in a substrate. (5) According to the formula, phase lag delta of a temperature response to heating light changes between 45 degrees and 90 degrees, when omegataus changes from 0 to infinity.
[0014] Next, the calculation of relative intensity to the laser beam change for heating of a reflected light change of the laser beam for temperature measurement on the strength on the strength is explained. It is a heat flow rate per [by

which the amplitude 1 was modulated] unit area [0015]
[Equation 6]

$$F(t) = \sin \omega t \qquad (1)$$

At this time, the Laplace transform of a skin temperature response is [0016].
[Equation 7]

$$\tilde{T}(\xi) = \frac{1}{b_s\sqrt{\xi}}\frac{\omega}{\omega^2+\xi^2}\frac{\coth(\sqrt{\xi\tau_f})+\beta}{\coth(\sqrt{\xi\tau_f})+\beta^{-1}} \qquad (2)$$

$$\tau_f = \frac{d^2}{\kappa_f} \qquad (3)$$

Here, the thermal diffusion property time amount (2) of a tauf:thin film is [0017] when [when beta and tauf are sufficient] small.
[Equation 8]

$$\tilde{T}(\xi) \approx \frac{1}{b_s\sqrt{\xi}}\frac{\omega}{\omega^2+\xi^2}\frac{1}{1+\sqrt{\xi\tau_s}} \qquad (4)$$

$$\tau_s = \frac{{b_f}^2}{{b_s}^2}\frac{d^2}{\kappa_f} \qquad (5)$$

It can approximate. Inverse Laplace transform of (4) is carried out, and the following formulas are obtained.
[0018]
[Equation 9]

$$T(t) = \frac{1}{b_s\sqrt{\xi}}\cdot\frac{\phi\sin\left(\omega t-\frac{3}{4}\pi\right)+(1+\phi)\cos\left(\omega t-\frac{3}{4}\pi\right)}{\phi^2+(1+\phi)^2} \qquad (6)$$

$$\phi = \sqrt{\frac{\omega\tau_s}{2}} \qquad (7)$$

Generally skin temperature can be written as follows.
[0019]
[Equation 10]

$$T(t) = A\sin(\omega t-\delta) \qquad (8)$$

The expedient top of count and the following are introduced.
[0020]
[Equation 11]

$$\delta = \frac{3}{4}\pi + \delta' \qquad (9)$$

It is [0021] from (6), (8), and (9).
[Equation 12]

$$A\cos\delta' = \frac{\phi}{b_s\sqrt{\omega}\{\phi^2+(1+\phi)^2\}} \qquad (10)$$

$$A\sin\delta' = -\frac{1+\phi}{b_s\sqrt{\omega}\{\phi^2+(1+\phi)^2\}} \qquad (11)$$

It is [0022] from (10) and (11).
[Equation 13]

$$\tan\delta' = -\frac{1+\phi}{\phi} \qquad (12)$$

It is [0023] from (7), (9), and (12).
[Equation 14]

$$\delta = \frac{3}{4}\pi + \arctan\left(- \frac{1+\sqrt{\frac{\omega\tau_x}{2}}}{\sqrt{\frac{\omega\tau_x}{2}}} \right) \qquad (13)$$

It is [0024] from (10) and (11).
[Equation 15]

$$A = \frac{1}{b_x\sqrt{\omega}} \cdot \frac{1}{\sqrt{\phi^2 + (1+\phi)^2}} \qquad (14)$$

It is [0025] when it calculates by carrying out inverse Laplace transform, without approximating (2).
[Equation 16]

$$\delta = \frac{3}{4}\pi + \arctan\left(\frac{\cosh^2\sqrt{\frac{\omega\tau_f}{2}}}{\cos^2\sqrt{\frac{\omega\tau_f}{2}}} \cdot \frac{\left(\tanh\sqrt{\frac{\omega\tau_f}{2}} + \beta\right)\left(\tanh\sqrt{\frac{\omega\tau_f}{2}} + \beta^{-1}\right)}{(\beta - \beta^{-1})\tan\sqrt{\frac{\omega\tau_f}{2}}} \right) \qquad (15)$$

It becomes. Naturally the amplitude A corresponding to (15) is calculable. At this time, it is [0026].
[Equation 17]

$$A = \frac{(\beta^{-1} - \beta)\tan\psi\sqrt{1 + \left(\frac{\cosh^2\psi}{\cos^2\psi} \cdot \frac{(\tanh\psi + \beta)(\tanh\psi + \beta^{-1})}{(\beta - \beta^{-1})\tan\psi} \right)^2}}{b_x\sqrt{\omega}\cosh^2\psi} \qquad (16)$$

$$\psi = \sqrt{\frac{\omega\tau_f}{2}} \qquad (17)$$

[0027] Drawing 2 is the conceptual diagram showing the system configuration of the minute field thermal property measuring device of this invention. X and the Y stage 1 are the device which can move to two dimensions of X and the direction of Y freely, and fine adjustment of the height of the vertical direction is attained by the micrometer 2. The sample 3 which should be measured is laid in X and Y stage, and it performs height adjustment by the micrometer 2 so that a laser beam may condense on a sample front face. After passing the microscope optical system 4 in the front face of a sample 3, the laser beam 5 for heating and the laser beam 6 for temperature measurement which lapped on the same optical axis are irradiated.
[0028] The laser beam 5 for heating is emitted from the laser 7 for heating which consists of CW argon laser with a wavelength of 514.5nm etc., and is modulated by the alternating current modulator 8. The laser beam 6 for temperature measurement is emitted from the laser 9 for temperature measurement which consists of CW He Ne laser etc. A driver 10 processes the alternating current of the predetermined frequency outputted from a function generator 11 to power required for the modulation of the laser beam for heating, and outputs it to the alternating current modulator 8. The alternating current modulator 8 modulates the laser beam for heating from the laser 7 for heating by the alternating current outputted from a driver 10.
[0029] On the optical axis of the microscope optical system 4, the 1st half mirror 12 and the 2nd half mirror 13 are arranged. The 1st half mirror 12 acts so that the laser beam 6 for temperature measurement which is made to reflect the laser beam 5 for heating generated from the laser 7 for heating in accordance with the optical axis of the microscope optical system 4, and is emitted from the laser 9 for temperature measurement may be passed in accordance with the optical axis of the microscope optical system 4. The 2nd half mirror 13 acts so that the laser beam 5 for heating and the laser beam 6 for temperature measurement which were reflected on the sample front face may be reflected in accordance with the incident light shaft of the optical detector 14, while passing the laser beam 5 for heating reflected by the 1st half mirror 12, and the laser beam 6 for temperature measurement which passed the 1st half mirror 12 in accordance with the optical axis of the microscope optical system 4. Here, optical DITAKUTA 14 is constituted by photo diode etc.
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[Translation done.]

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] It is the explanatory view showing the property of the thermal diffusion of a thin film and a substrate two-layer model of a parameter.
[Drawing 2] It is the conceptual diagram showing the system configuration of the minute field thermal property measuring device of this invention.
[Drawing 3] It is drawing showing the relation of the phase lag over thickness.
[Description of Notations]
1 X, Y Stage
2 Micrometer
3 Sample
4 Microscope Optical System
12, 13, 16 Half mirror
14 Optical Detector
15 Band Pass Filter
17 CCD Camera
18 Monitor

[Translation done.]